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A STATISTICAL COMPARISON OF WINTER-SUMMER ROCKETSONDE-RADIOSONDE TEMPERATURES IN THE 20- TO 34-KILOMETER REGION OF THE STRATOSPHERE

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ABSTRACT

An investigation to determine whether rocketsonde temperatures are significantly different from radiosonde temperatures was made using published data for Wallops Island, Va. Statistical comparison between the Arcasonde 1A and ESSA's hypsometer-equipped "outrigger thermistor" type radiosonde revealed their measurements to be significantly different. Examination of the mean temperatures yielded by each measuring system for the winter and summer seasonal data revealed a constant difference below 26 km, while above this altitude the difference increased with altitude. The range of winter-summer mean temperatures computed from each system also showed good agreement except above 26 km where the range increased at a different rate. It is believed these differences in the temperature profiles may be caused by radiation influences acting differently on each sensor. The need for further investigation of these differences is indicated.

1. INTRODUCTION

Incompatibility between measured radiosonde and rocketsonde temperatures has been shown to exist by Finger and Woolf (1966) and has also been reported on by Belmont et al. (1964) and Wright Instruments, Inc. (1961); similarly, Craig et al. (1967) have reported differences between measurements made with rocketsonde and radiosonde temperature sensors flown on the same radiosonde instrument. The radiosonde is considered to be the standard from which pressure, altitude, and temperature values are used as the initial values for determining pressures and densities at rocketsonde altitudes. It is also customary to base the reliability of measured rocketsonde temperatures on their agreement with radiosonde temperatures obtained close in time. Hodge and Harmantas (1965) in their radiosonde compatibility study reported that the radiosonde exhibits some variability in its measurements. They found that this variability can be attributed to a combination of causes, e.g., resolution of ground equipment and evaluators, different radiosonde manufacturers and production lots, baseline check errors, computational and plotting procedures, pressure cell errors, etc. However, radiosonde variabilities cannot be considered the sole reason for the differences noted; Miller et al. (1968) have shown that variability also exists in rocketsonde measurements. They feel that this may be due to real atmospheric fluctuations, in addition to other measurement variabilities. Also to be considered is that most rocketsonde techniques were adapted from radiosonde methods; in fact, most of the ground equipment used in making radiosonde observations is also used in making rocketsonde observations. Possibly then, some of the causes of radiosonde variability as found by Hodge and Harmantas (1965) could also account for rocketsonde variability. It is important, therefore, that these observed differences between rocketsonde and radiosonde measurements be investigated to determine whether they are significant.

Because the sensors, telemetry, and ground equipment of both systems are essentially the same and the observations are made close in time, statistical methods were used to test the temperature differences. More specifically, the paired observations t-test was used to test for significant differences; it was assumed that stratospheric conditions remained unchanged between the measurements made within each pair. Data published in the *Data Report, Meteorological Rocket Network Firings* (Environmental Science Services Administration, 1965–1967) and in the "EXAMETNET Data Report Series" (Schellenger Research Laboratory, 1966–1967) were used to make the comparisons. These data reports provided a large number of daytime-only soundings plus a smaller number of nighttime-only soundings.

Statistical testing procedures require that the number of variables be a minimum. The available soundings, however, contained variables whose interaction could conceivably influence the results. In order to reduce the number of variables, the following restrictions were observed in selecting data. First, only Wallops Island, Va., soundings were used. Secondly, investigation was limited to temperatures obtained from the Arcasonde 1A* and ESSA's hypsometer-equipped "outrigger thermistor" type radiosonde. Thirdly, the stratosphere was assumed to have two seasons, winter (October through April) and summer (May through September). Finally, only rocketsonde-radiosonde observations obtained within plus or minus 6 hr of each other were compared.

2. STATISTICAL TESTS

To remove persistence that may have existed between the paired observations, only pairs separated by 24 hr or more were selected. These were then edited further (using a graphical editing process) to remove those observations

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TABLE 1.—*Date and launch times (GMT) of the Arcasonde 1A and time differences between the Arcasonde 1A and radiosonde observations for the stratospheric winter (Oct.–Apr.). Time differences with a minus sign indicate the radiosondes were released prior to the Arcasondes.*

Year	Day	Time	Time difference	Year	Day	Time	Time difference
1965	Oct. 25	1938	+1:25	1967	Mar. 24	1913	−1:58
	Oct. 26	1834	−1:19		Mar. 31	1844	−0:44
	Oct. 27	1942	−2:27		Apr. 4	1119	−0:23
	Nov. 4	1911	−2:05		Apr. 6	2143	+1:32
	Nov. 8	2013	−3:04		Apr. 11	1825	+1:05
	Nov. 10	1819	+1:01		Apr. 14	1501	+2:14
	Nov. 24	1716	+0:59		Apr. 20	1806	+1:24
	Dec. 1	1734	+1:06		Apr. 26	1451	−3:23
	Dec. 8	2031	−2:15		Oct. 5	1413	−2:58
	Dec. 15	1921	−2:06		Oct. 6	1834	−1:34
1966	Jan. 20	1543	−4:28	1967	Oct. 12	1530	−4:15
	Mar. 18	1517	−4:02		Oct. 20	1350	−2:35
	Nov. 9	2031	−3:16		Oct. 25	1417	−2:17
	Nov. 16	1606	+1:09		Oct. 27	1455	−3:40
1967	Jan. 18	1604	−4:49		Nov. 3	1726	−6:11
	Jan. 25	1639	−5:24		Nov. 17	1542	−4:27
	Jan. 31	1935	−3:00		Nov. 21	1515	−4:00
	Feb. 1	1838	−2:06		Nov. 29	1953	−7:38
	Feb. 3	1825	+1:55		Dec. 8	1759	−5:59
	Feb. 15	1651	+1:04		Dec. 13	1816	−3:46
1967	Mar. 8	1521	+1:54	1967	Dec. 19	2041	+2:34

TABLE 2.—*Date and launch times (GMT) of the Arcasonde 1A and time differences between the Arcasonde 1A and radiosonde observations for the stratospheric summer (May–Sept.). Time differences with a minus sign indicate the radiosondes were released prior to the Arcasondes.*

Year	Day	Time	Time difference	Year	Day	Time	Time difference
1965	Sept. 3	1525	+2:05	1967	May 25	1846	+2:36
1966	June 1	1607	+1:08		June 2	1846	−2:36
	June 3	1446	−3:31		June 7	1432	−3:17
	June 24	1501	−3:46		June 15	1742	−2:10
	June 29	1436	−3:21		June 21	1414	−0:36
	July 13	1914	−1:59		June 28	1501	−3:13
	July 15	1411	−2:56		July 5	1442	−2:17
	July 22	1446	−3:31		July 26	1414	−2:59
	Aug. 19	1538	−4:23		July 28	1359	−10:01
	Aug. 26	1954	−2:39		Aug. 16	1730	+1:04
1966	Aug. 29	1631	+1:14	1967	Aug. 18	1411	−2:56
	Sept. 7	1535	−4:19		Aug. 25	1417	−3:02
	Sept. 9	1550	−4:40		Aug. 30	1818	−2:48
	Sept. 16	1935	−3:24		Sept. 6	1435	+3:25
	Sept. 23	1848	−2:33		Sept. 8	1418	−3:03
1967	May 3	1407	−2:44		Sept. 15	1345	−2:30
	May 4	2033	+1:27		Sept. 20	1529	−4:19
	May 10	1758	−2:38		Sept. 22	1530	+1:45
	May 17	1429	−3:19		Sept. 27	1445	+2:30

that contained obvious discrepancies. Approximately 35 samples from each season were available for testing; about half this number were available from the upper altitudes. Tables 1–3 give the Arcasonde launch dates, times, and time differences from radiosonde release times for each season and for the nighttime data.

The means and standard deviations of the temperature differences were calculated for nine altitudes in the 20- to 34-km region. These data were used in the t-test. Means, variances, and standard deviations were also calculated for the temperatures obtained from each system. The calculations and tests were made on the winter- and summer-season daytime data, and these seasonal data were then combined to provide total yearly values for additional testing. Nighttime soundings, although few in number (six to 19), provide a measure of comparison with the daytime data.

The data distribution was considered to be normal; but because of the sample size, Student's t-test was employed to test the temperature differences for significance. The difference d is given by

$$d=X-Y$$

where X represents the Arcasonde temperature and Y the radiosonde temperature.

After formulating the hypothesis that the differences were equal to zero, a two-tailed t-test at the 95-percent level of significance was applied to the measurements. It should be noted that the paired observations test is a powerful test and will reject the hypothesis more times than it will accept it. This is because measurements when made in pairs are expected to yield a high correlation that will tend to minimize the variance, thus increasing the calculated value of t.

TABLE 3.—*Date and launch times (GMT) of the Arcasonde 1A and time differences between the Arcasonde 1A and radiosonde observations for all nighttime observations. Time differences with a minus sign indicate the radiosondes were released prior to the Arcasondes.*

Year	Day	Time	Time difference	Year	Day	Time	Time difference
1965	Nov. 11	0440	+1:23	1966	Oct. 5	0007	+5:08
	Nov. 25	0429	+0:58		Aug. 12	2224	+2:04
	Dec. 2	0623	+1:07		Aug. 16	0706	+2:04
	Dec. 9	0454	+1:08		Aug. 17	2340	+2:15
	Dec. 16	0601	+0:57		Aug. 28	0451	−2:35
1966	Mar. 18	0231	−3:16		Aug. 30	0121	−7:36
	Oct. 1	0033	−6:04		Sept. 17	0402	+1:13
1967	Feb. 14	0722	+0:58	1967	May 5	0726	−3:26
	Apr. 4	1002	+0:54		Aug. 9	0043	+2:12
	Apr. 5	0129	−0:46		Aug. 9	0130	+1:25
	Apr. 5	0358	−3:15				

The means, variances, and standard deviations for the temperatures measured by each system and the t-test results are given in table 4.

3. DISCUSSION

The two-tailed t-test showed that one-half the observed t-values exceeded the critical values (table 4). Therefore, the hypothesis that the differences equaled zero was rejected. These differences could have been caused by space and time differences, or measurement error in the systems, or both. Certainly, differences due to variability in space and time are expected to occur, but how much can be attributed to each is difficult to determine with the available samples. Determining the magnitude of the measurement error is likewise difficult since an absolute standard by which a measurement can be compared does not exist at this time. Such an absolute standard should not be confused with the accepted procedure of using the radiosonde measurements as a reference or base from

TABLE 4.—*Statistical results for winter, summer, and all nighttime and daytime data. Results of the t-test for the differences are also shown.*

Data		Bead thermistor $\bar{X}$	Bead thermistor S_x^2	Bead thermistor S_x	Rod thermistor $\bar{Y}$	Rod thermistor S_y^2	Rod thermistor S_y	Differences $\bar{d}$	Differences S_d^2	Differences S_d	t-test t_{obs}	t-test $t_{0.95}$	f
20 km	Winter	−58.291	5.779	2.404	−59.311	4.571	2.138	1.020	3.752	1.934	3.120	1.960	34
	Summer	−55.614	2.832	1.683	−56.083	3.984	1.996	0.469	1.843	1.358	2.072	1.960	35
	$Year_n$	−57.929	6.225	2.495	−58.282	7.366	2.714	0.353	2.156	1.468	0.992	2.120	16
	$Year_d$	−56.934	6.042	2.458	−57.675	6.854	2.618	0.741	2.821	1.679	3.719	1.960	70
23 km	Winter	−55.519	7.535	2.745	−56.603	6.964	2.639	1.083	2.095	1.447	4.491	1.960	35
	Summer	−51.678	3.553	1.885	−52.067	2.042	1.429	0.389	1.579	1.257	1.857	1.960	35
	$Year_n$	−54.161	12.404	3.522	−54.650	13.646	3.694	0.489	2.589	1.609	1.290	2.110	17
	$Year_d$	−53.599	9.205	3.034	−54.335	9.653	3.107	0.736	1.933	1.390	4.493	1.960	71
24 km	Winter	−54.281	11.560	3.400	−55.250	9.114	3.019	0.969	2.149	1.466	3.966	1.960	35
	Summer	−50.137	3.618	1.902	−50.603	2.952	1.718	0.466	2.149	1.484	1.936	1.960	37
	$Year_n$	−53.821	16.769	4.095	−53.495	16.704	4.087	−0.326	2.274	1.508	−0.942	2.101	18
	$Year_d$	−52.153	11.724	3.424	−52.864	11.337	3.367	0.711	2.210	1.487	4.113	1.960	73
25 km	Winter	−53.397	12.096	3.478	−53.959	11.296	3.361	0.562	3.784	1.946	1.757	1.960	36
	Summer	−48.923	3.007	1.734	−49.146	2.696	1.642	0.229	1.667	1.291	1.049	1.960	34
	$Year_n$	−52.458	20.995	4.582	−52.368	19.918	4.463	−0.089	3.322	1.823	−0.213	2.101	18
	$Year_d$	−51.222	12.645	3.556	−51.619	12.888	3.590	0.397	2.770	1.664	2.024	1.960	71
26 km	Winter	−53.297	10.420	3.228	−53.385	8.934	2.989	0.088	3.951	1.988	0.254	1.960	32
	Summer	−47.766	1.687	1.299	−47.745	1.847	1.359	−0.021	1.428	1.195	−0.094	2.048	28
	$Year_n$	−50.900	18.207	4.267	−50.900	14.631	3.825	0.000	4.781	2.187	0.000	2.101	18
	$Year_d$	−50.710	13.980	3.739	−50.747	13.587	3.686	0.037	2.731	1.653	0.176	1.960	61
28 km	Winter	−50.148	9.413	3.068	−50.571	9.709	3.116	0.423	2.808	1.676	1.405	2.042	30
	Summer	−44.262	2.890	1.700	−44.945	3.172	1.781	0.683	1.036	1.018	3.614	2.048	28
	$Year_n$	−50.267	31.237	5.589	−50.587	27.836	5.276	0.320	5.225	2.286	0.542	2.145	14
	$Year_d$	−47.303	14.961	3.868	−47.852	14.478	3.805	0.548	1.937	1.392	3.049	1.960	59
30 km	Winter	−46.360	12.946	3.598	−47.083	11.533	3.396	0.723	3.236	1.799	2.201	2.045	29
	Summer	−40.284	5.406	2.325	−41.496	4.840	2.200	1.212	2.119	1.455	4.165	2.064	24
	$Year_n$	−44.885	26.204	5.119	−45.954	27.531	5.247	1.069	6.479	2.545	1.515	2.179	12
	$Year_d$	−43.598	18.680	4.322	−44.544	16.225	4.028	0.945	2.740	1.655	4.235	1.960	54
32 km	Winter	−43.324	14.357	3.789	−43.486	13.032	3.610	0.162	5.123	2.263	0.328	2.086	20
	Summer	−36.492	7.486	2.736	−38.092	4.567	2.137	1.600	2.595	1.611	3.581	2.179	12
	$Year_n$	−41.760	41.293	6.426	−43.460	32.036	5.660	1.700	3.145	1.774	3.031	2.262	9
	$Year_d$	−40.712	22.782	4.773	−41.424	16.597	4.074	0.712	4.552	2.134	1.945	1.960	33
34 km	Winter	−40.707	39.614	6.294	−42.207	32.274	5.681	1.500	11.734	3.425	1.639	2.160	13
	Summer	−31.911	15.603	3.950	−34.755	9.370	3.061	2.844	5.768	2.402	3.552	2.306	8
	$Year_n$	−35.900	22.648	4.759	−40.050	45.347	6.734	4.150	5.343	2.311	4.399	2.571	5
	$Year_d$	−37.265	48.553	6.968	−39.291	36.301	6.025	2.026	4.292	2.075	4.675	2.074	22

which pressure and density computations at rocketsonde altitudes can be made.

It was expected that the standard deviations would be larger for the bead thermistor temperatures (because of the bead's response characteristics) than those measured with the rod thermistor. This expectation was not realized. As shown in table 4, the Arcasonde standard deviations (S_x) were similar to, and in some instances less than, the radiosonde's (S_y); only at 32 and 34 km were they larger. Comparisons of the standard deviations for the winter and summer data showed the measurement variability to be greater for the winter-season observations. This suggests that solar effects could have a greater stabilizing influence during the summer, or that actual atmospheric variability is greater in winter. It should be noted that the standard deviations for all the data became larger with increasing altitude.

Comparison of the winter-summer and nighttime-daytime mean temperatures (figs. 1 and 2) show that the radiosonde temperatures were lower than the Arcasonde's. Except for minor perturbations of the nighttime profiles between 23 and 26 km (fig. 2), the differences between the mean temperatures were constant to about 24 km. Above 26 km, the mean temperatures diverged. The mean-temperature differences $\bar{d}$ for the winter-summer example (fig. 3A) show that between 20 and 24 km the radiosonde temperatures were lower than the Arcasonde's by about 1°C during the winter and 0.5°C during the summer; the differences were slightly less for the nighttime-daytime example (fig. 3B). It is not understood why the mean temperatures diverged above 26 km; possibly, radiation could be affecting each sensor differently. Armstrong (1965) has reported that the height at which radiation error becomes a major problem depends on the magnitude of the source of error, the size and shape of the sensor, the rate of ventilation, and the coefficient of absorption of the element for the radiation being received and radiated. These are known to be different for the bead and rod thermistors. Similarly, on tests made at Wallops Island during May 1966, Craig et al. (1967) reported that the sensors agreed quite well up to about 24 to 25 km where the differences in temperature began to drift apart with increasing altitude. In these tests, the 10-mil bead, STS–1 sensor (used by White Sands Missile Range) and

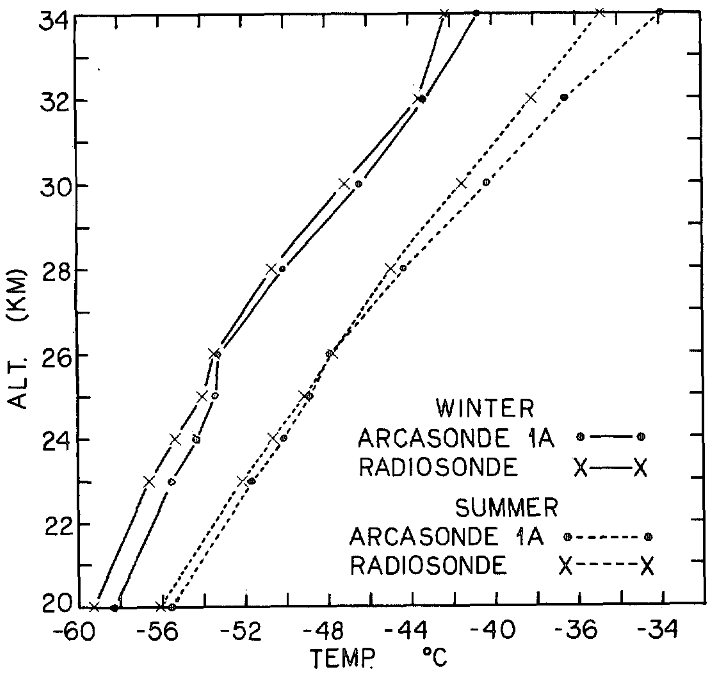

FIGURE 1.—Arcasonde 1A and radiosonde mean-temperature profiles for winter and summer seasons at Wallops Island, Va.

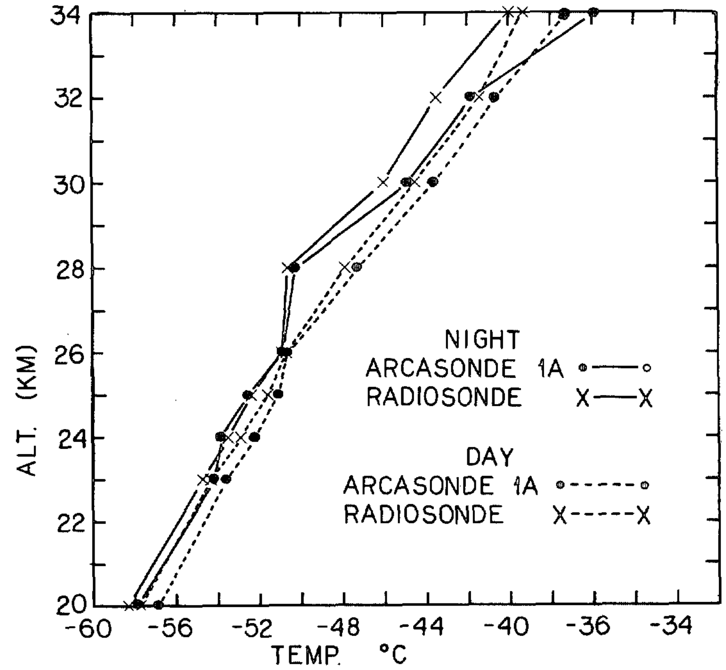

FIGURE 2.—Arcasonde 1A and radiosonde mean-temperature profiles for all night and day data at Wallops Island, Va.

the ML–419 rod thermistor were flown on the same radiosonde.

The results of these current comparisons raise the question, why does the systematic difference occur between 20 and 24 km? It might be hypothesized that the radiosonde balloon cools almost to the tropopause temperature and, as it rises into the relatively warmer stratospheric air, remains colder than ambient because of its thermal lag. Perhaps then, the radiosonde's thermistor was cooler than ambient because it was washed in the flow of air cooled by contact with the rising balloon. Brasefield (1948) in his investigation of the outrigger- and ducted-type thermistor mounts reported an increase in temperature of about 1°C immediately after balloon burst.

The seasonal ranges of the mean temperatures reported by each measuring system also were found to increase at different rates with increasing altitude. The ranges of the winter-summer mean temperatures (fig. 4A) for the Arcasonde were 2.7°C at 20 km and 8.8°C at 34 km; the ranges reported by the radiosonde were 3.2°C at 20 km and 6.4°C at 34 km. Although the magnitude of the seasonal range was different for each system, it is noteworthy that the differences between the ranges were nearly constant (0.5°C to 0.6°C) up to about 26 km and diverged above this altitude. This again suggests that the cause may be radiation affecting each system differently; otherwise, the differences should have remained essentially constant to 34 km. The ranges of the night-day mean temperatures for each system (fig. 4B) were found to be considerably less than the winter-summer ranges. The nighttime profiles were not as well defined as the winter-summer profiles, probably because of the smaller number of samples.

Wallops Island mean temperatures for the period 1961–1967 were computed for six winter and summer seasons

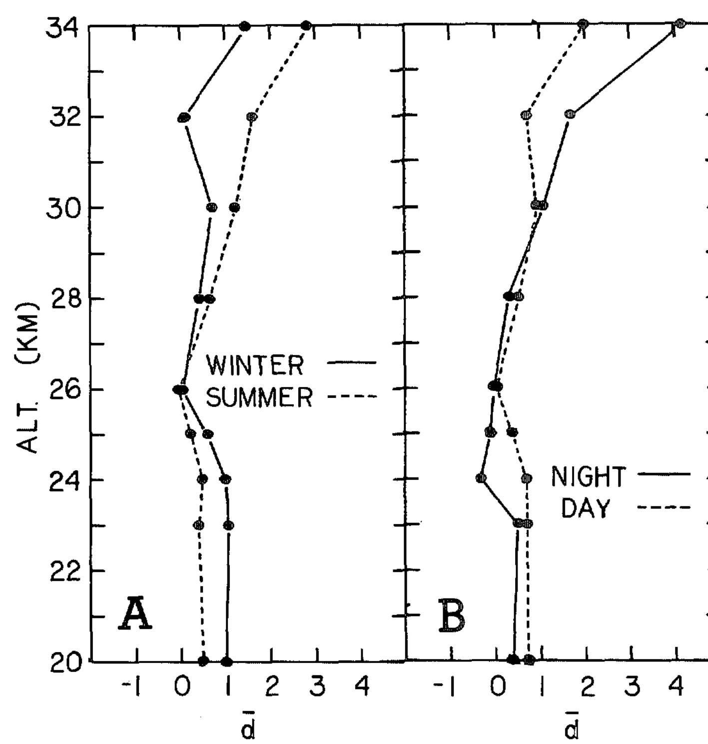

FIGURE 3.—(A) differences between the Arcasonde 1A and radiosonde mean temperatures for the winter and summer seasons. Positive values indicate colder radiosonde temperatures. (B) differences between the Arcasonde 1A and radiosonde mean temperatures for night and day. Positive values indicate colder radiosonde temperatures.

(table 5) using the summary data published in the WDC–A rocket-data reports (Environmental Science Services Administration, 1965–1967). It should be noted that the summary contains temperatures measured by a number

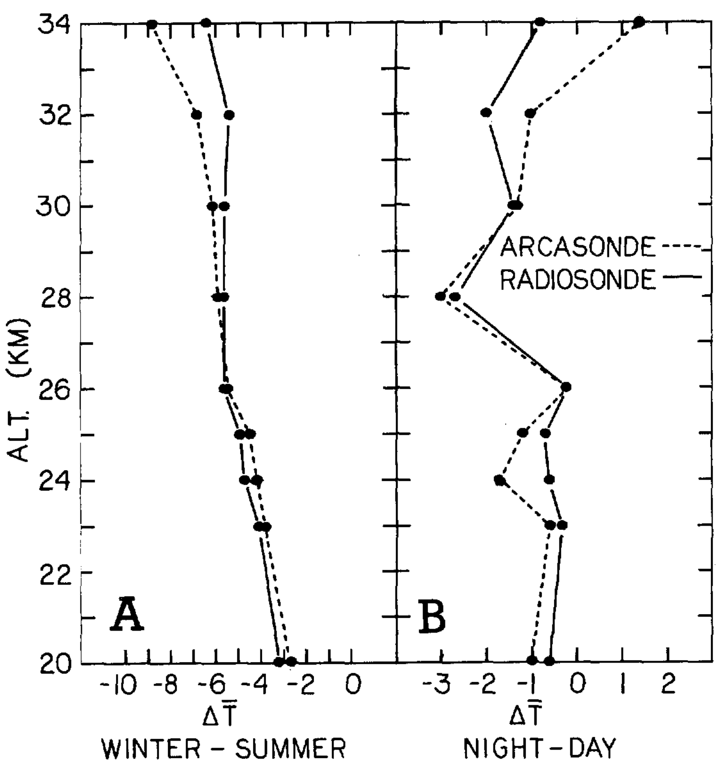

FIGURE 4.—(A) profiles of winter-summer mean-temperature range for both the Arcasonde and radiosonde data. (B) profiles of night-day mean-temperature range for both the Arcasonde and radiosonde data.

TABLE 5.—*Rocketsonde mean temperatures vs. altitudes for each season and for the 6-yr period for Wallops Island, Va. The data are for the period 1961–1967.*

	Altitude (kilometers)								
	20	23	24	25	26	28	30	32	34
Winter	−58.8	−55.1	−54.2	−53.4	−52.3	−49.4	−46.1	−42.3	−38.2
Summer	−56.2	−51.7	−50.2	−49.0	−47.4	−44.1	−40.8	−36.5	−31.1
Year	−57.4	−53.3	−52.0	−51.1	−49.7	−46.6	−43.4	−39.3	−34.5

of different rocketsonde types. Radiosonde temperatures were also obtained for the period 1964–1967 (table 6) from the Monthly Summary of Radiosonde Observations (WBAN-33). While the two data samples are not for the same time period, it is believed that the derived values are representative of the thermal structure over Wallops Island. The seasonal profiles (fig. 5) are very similar to those shown in figure 1. Mean temperatures for White Sands Missile Range (WSMR) were also derived from the rocket-data reports for the same 6-yr period (this site is closest in latitude to Wallops). The "White Sands Missile Range Reference Atmosphere" (Range Reference Atmosphere Committee, 1964) was used to obtain the radiosonde mean-temperature profile (this publication does not report radiosonde type). As shown in figure 6, temperature profiles for WSMR are different from those for Wallops Island. One may speculate, as has been pointed out by Armstrong (1965), whether the underlying

TABLE 6.—*Radiosonde temperatures and altitudes vs. pressures at Wallops Island, Va. The data are for the period 1964–1967.*

		Pressure (millibars)								
		60	50	40	30	25	20	15	10	7
Winter	Height	19403	20507	21910	23733	24895	26314	28190	30862	33260
	Temp.	−60.5	−59.3	−57.7	−55.9	−54.7	−53.1	−51.0	−46.6	−43.0
Summer	Height	19708	20865	22297	24162	25388	26831	28752	31505	33952
	Temp.	−57.4	−55.2	−53.0	−50.2	−48.6	−46.3	−43.3	−39.1	−35.0
Year	Height	19533	20686	22071	23912	25100	26529	28424	31130	33548
	Temp.	−59.0	−57.3	−55.7	−53.5	−52.2	−50.3	−47.8	−43.5	−39.7

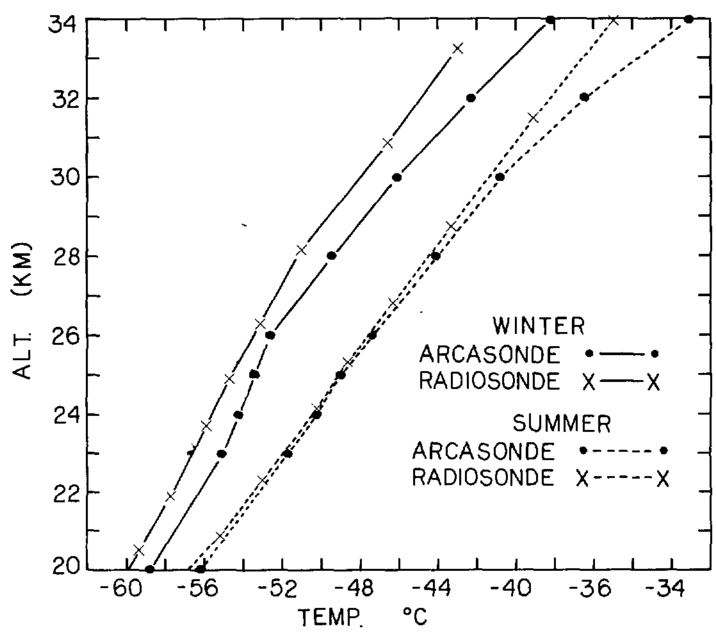

FIGURE 5.—Profiles of the 6-yr mean rocketsonde temperatures and 3-yr mean radiosonde temperatures for Wallops Island, Va.

surfaces at each location could be affecting the sensors or atmosphere, or both, differently. Wallops Island launches its rockets over the Atlantic Ocean, and its radiosondes normally drift seaward because of the predominantly westerly winds; WSMR's observations are made over the desert.

4. CONCLUSIONS AND FINAL COMMENTS

Statistical comparison has shown that temperatures measured by Arcasondes and radiosondes at Wallops Island, Va., between October 1965 and December 1967 were significantly different. It was evident from the temperature profiles (figs. 3A, B) that the radiosonde temperature was lower than the rocketsonde by 1°C during the winter and 0.5°C during the summer. Above 26 km, the difference between the mean temperatures increased with altitude. Upon examination of the seasonal ranges of the mean temperatures, similar conditions were found to exist for each measuring system. If these differences are due to space and time differences or measurement error, then perhaps the present method of using the supporting radiosonde data should be examined.

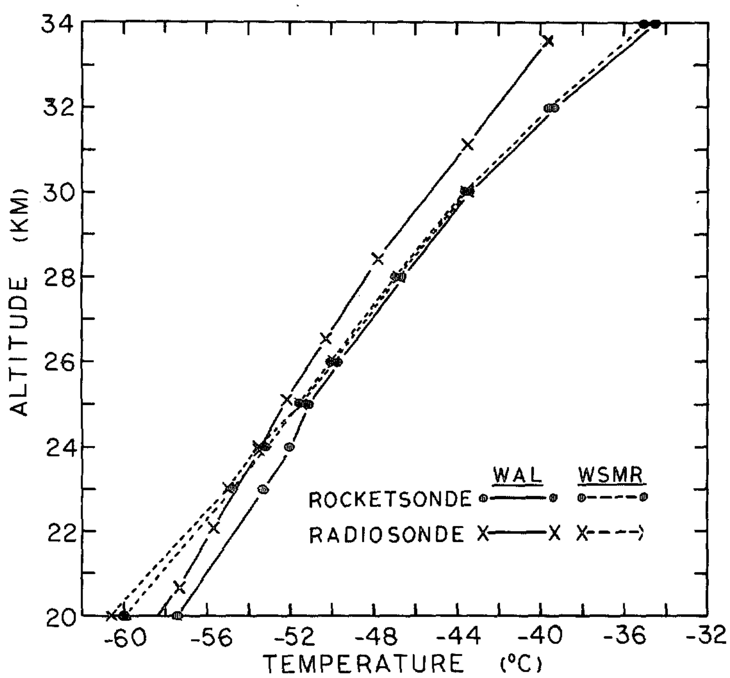

FIGURE 6.—Profiles of the yearly averages of the rocketsonde and radiosonde temperatures at Wallops Island, Va., and White Sands Missile Range, N. Mex.

Accordingly, the use of the radiosonde for obtaining initial data for pressure and density computations at rocketsonde altitudes may need to be replaced. Finally, differences between temperature profiles for Wallops Island and WSMR were found to exist; WSMR radiosonde and rocketsonde temperatures showed excellent agreement in contrast to Wallops Island radiosonde and rocketsonde temperatures.

Although it is difficult to conclude what the real causes of these differences are, radiation influences affecting each system differently may be the major contributor to the error. It is suggested that further studies aimed at determining the influence of radiation reflection and emission from the earth's surface, and the absorption and emission characteristics of the radiosonde and Arcasonde sensors, be undertaken.

Radiosonde techniques may not be compatible with rocketsonde techniques mainly because of the latitude allowed the observer in the selection of significant data. Therefore, it is further suggested that an investigation of balloon-borne observational methods be undertaken in an effort to study their effects on rocketsonde data. It would also be interesting to see results of more radiosonde observations made with bead and rod thermistors mounted on the same instrument. The use of radar to measure the radiosonde heights should be a primary requisite. This would help in determining quantitatively the amount of measurement error that may exist.

One final comment is in order. Although the radiosonde involved in this study was equipped with a hypsometer for determining pressure, it is possible that an error could exist in the radiosonde heights due to pressure measurement error. This was not considered here, primarily because the error due to this source amounts to about 200–300 m. After examining figures 1 and 2 again, it is obvious that the temperature differences could be decreased below 26 km by a height adjustment of the curve, but this will not materially change anything above 26 km.

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